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Wright-Patterson Air Force Base, Ohio

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AFIT/GE/ENG/88D-52

ON THE IMPULSE RESPONSE

OF MONOPULSE RADARS

THESIS

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THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Electrical Engineering

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December 1988

Preface

The purpose of this study was to develop an analytical model to determine the response of an amplitude-amplitude monopulse radar due to an impulsive input signal.

It was determined the filters in each channel would have the greatest impact on the response of the radar due to an impulsive signal. Inverse Laplace transform techniques were used to determine the impulse response of both a three-pole filter and a five-pole filter.

In performing this analysis and writing this thesis I have had a great deal of help from others. I want to thank my thesis advisor Dr. Vittal Pyati for his assistance. I also want to thank Capt David Reddy of the Air Force Electronic Warfare Center for sponsoring this effort and for his encouragement. I also want to thank all the guys in the Low Observables class of December 1988 for making the time spent at AFIT an enjoyable experience. Finally, I want to thank my wife Patsy and our two children Christy and Jeffrey for their understanding and patience during my studies at AFIT.

Dennis L. Tackett

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Abstract

The purpose of this study was to develop an analytical model to determine the response of an amplitude-amplitude monopulse radar to an impulsive input signal. This study was sponsored by the Air Force Electronic Warfare Center at Kelly AFB and represents a first step for determining if impulsive jamming has any merit against monopulse radar systems.

From a literature review, it was determined that the receiver components most affected by an impulsive signal were filters in the receiver channel. Inverse Laplace transform techniques were used to determine the impulse response of a three-pole and a five-pole filter. A model of a logarithmic amplifier was also used. A fortran computer program was written to simulate the response of the radar system. The computer program allows for the poles of the filters to be changed to simulate imbalances between the receiving channels of the radar.

The results of the analyses showed that an impulsive signal would not cause a substantial tracking error until four to six seconds after the pulses arrive at the input of the filter, which is well out of the range gate. This signal may produce angle errors in the angle circuits of the radar without being detected by the range circuitry or the

operator. It is recommended that experimental results using an impulsive electronic countermeasures signal against a monopulse radar be obtained.

ON THE IMPULSE RESPONSE OF MONOPULSE RADARS

I. Introduction

Overview

This thesis presents an analysis of the effects an impulsive type of electronic countermeasures (ECM) signal has on an amplitude-amplitude monopulse radar. The Air Force Electronic Warfare Center at Kelly AFB has sponsored this effort. This chapter presents background material, a problem statement, the current knowledge on the subject, the assumptions used in the analysis, the scope of this effort, and the approach used to solve this problem.

Background

Electronic Combat has become a necessary element in all successful Air Force operations and is deemed as critical to the mission as fuel and armament. However, an inevitable problem of electronic combat is that its employment tends to alert air defense forces to the presence of the penetrating aircraft. Passive and off-board countermeasures help alleviate this problem but they consume mission space and weight. An onboard, active ECM system which can negate the threat in a covert fashion is needed.

Concepts such as power and time management of the ECM system help reduce exposure to the threat but they only limit the number of threats alerted. According to the Air Force Electronic Warfare Center, attention must be given to the development of ECM techniques which are inherently covert so that the combination of these ECM techniques with power and time management can secure an acceptable level of protection and covertness. Very low duty cycle jamming shows promise towards achieving this goal.

Problem

The purpose of this thesis is to develop an analytical model of an amplitude-amplitude monopulse radar system to determine the response to impulsive or transient ECM waveforms. An analysis of the effects of low duty cycle jamming on a monopulse radar can then be investigated by modeling the low duty cycle jamming as an impulse function.

Summary of Current Knowledge

Monopulse Radar Theory. The theory of monopulse radars is well documented. Rhodes first postulated the requirements for a monopulse radar system in 1959. He describes monopulse as a concept of precision direction finding of a pulsed source of radiation (6:1). A monopulse radar can determine the angular position of a target on the basis of only one returned pulse. Hence, it is inherently

immune to angle errors caused by an ECM signal such as noise or inverse gain jamming.

In an amplitude-amplitude monopulse radar system angle sensing is achieved with an antenna that generates two beams in each coordinate plane. The amplitude imbalance between the receiver channels associated with each beam is directly related to the tracking angular error. This amplitude difference is zero when the received signals in the two beams are equal. Tracking is performed by slewing the antenna pedestal until the received signals have equal amplitude (4:75). In one type of amplitude-amplitude monopulse system the receiver channels contain logarithmic amplifier-detectors to provide large dynamic range. The output of the logarithmic amplifiers is fed to a subtraction circuit which provides the magnitude and direction of the error signal. The error signal is used to actuate a servo-control system to position the antenna beam tracking axis on the target. The reader is referred to Sherman (7) or Leonov and Fomichev (4) for a more detailed description of an amplitude-amplitude monopulse radar system.

<u>ECM Interference Effects on Monopulse Radars.</u> ECM may be defined as the employment of electronic devices and techniques for the purpose of destroying or degrading the effectiveness of an enemy's electronic aids to warfare. Jamming is the radiation or reradiation of signals in such a way as to interfere with the operation of a radar by

saturating its receiver by producing false targets (9:III-1). Leonov and Fomichev state:

> The basic objective of an ECM signal is to distort the information in the receiving channels of radars and to create spurious information, making it difficult to detect targets, measure their coordinates, and organize a defensive response to dangerous targets [4:223].

Although a monopulse radar is inherently immune to errors caused by some types of ECM or other types of interference, angle errors can still occur due to unequal responses of the receiver channels (4:169). The impulsive ECM signal will attempt to take advantage of the unequal response of the receiver channels.

High-level ECM signals can cause an effective loss in receiver sensitivity with a consequent loss in detection range while all evidence of their presence is effectively kept from the display (9:29-2). Jamming can disrupt the operation of a receiver channel by overloading the channel. Saturation of any element in the tracking loop will destroy the amplitude variations in the target signal, in turn partially or totally preventing the formation of the correct error signal. If a narrowband automatic gain control is used in the radar receiver, switching off the ECM signal may break the tracking loop for the time necessary for the sensitivity of the receiver to stabilize to the level of the reflected target signal (4:235-236). High-power microwaves could upset any system that depends on electronic signals

for its operation. At very high power levels the ECM signal will burn out semiconductor devices and at lower powers the ECM signal can trigger spurious signals in the receiver that might jam or temporarily debilitate a device (2:50).

Analytical Models. An analytical model of a system is a mathematical description of the processes of the system. It allows the estimation of system performance characteristics without actually constructing the physical system. Analytical models of monopulse systems have been developed by Leonov and Fomichev (4:303), Golden (3:288), and MacAulay Brown Inc. (5).

Leonov's and Fomichev's Model. Leonov and Fomichev presented analytical models of both amplitude-amplitude and amplitude-sum-and-difference monopulse radars. They use Fourier analysis techniques to transform from the frequency domain to the time domain and vice-versa. In their radar model, a pulse is formed at the input of each channel, the amplitude of which depends on the offset angle between the target and the antenna tracking axis. Amplitude and phase distortions can be added to the pulses to study their influences. The distorted pulse is mixed additively with Gaussian white noise to obtain the desired signal-to-noise ratio. A linear filter, whose impulse response is matched to the undistorted waveform, and a Hamming filter is used to obtain desired range sidelobe reduction. The pulses are then detected by extraction of the envelope of the

signal at the output of the linear filter. The output of the filters is then added and subtracted and these outputs are provided to a division circuit. The output of this division circuitry is the error signal (4:320).

Golden's Model. Golden presented models of various types of monopulse radar receivers. His model of an amplitude-amplitude monopulse radar does not include filters in the channels. This does not allow for a correct analysis of an impulsive type of ECM because the filter response will greatly affect the error signal due to this ECM signal. Golden went into great detail in determining the effect of an impulsive ECM signal on the output of an intermediate amplifier (IF) with automatic gain control. This type of amplifier is used with sum-and-difference monopulse systems. His conclusion is the effects due to an impulsive ECM technique is sensitive to the parameters of the radar circuitry (3:419).

MacAulay Brown's Model. MacAulay Brown Inc. developed an analytical model of monopulse radars while under contract to the United States Air Force. Their model has been implemented on a computer and can be used to evaluate ECM techniques which exploit hardware imperfections and operational factors in radar systems (5:1). Their model consists of an antenna system, channelized receivers, demodulator, and servosystems. The antenna is organized in quadrants with each sub-antenna separated by a squint angle

in azimuth and elevation. The receiver is composed of filters, signal compression, and detection. The two types of signal (amplitude) compression are modeled as logarithmic amplifiers and automatic gain control. MacAulay Brown's model allows for the evaluation of ECM techniques by determining angle errors caused by the ECM (5:4). The importance of MacAulay Brown's model is it allows the user to include imperfections in the radar model which can be exploited by an ECM signal. MacAulay Brown's model is basically used for a steady-state analysis of a monopulse receiver. The model would have to be modified to allow the effects of impulsive ECM to be analyzed.

Scope

This thesis is limited to the analysis of an amplitude-amplitude monopulse radar system. The other types of monopulse radars will not be considered.

Approach

The functional components of the amplitude-amplitude monopulse radar were analyzed to determine the output due to an impulsive input. The filters were determined to be the components which had the greatest impact on an impulsive input. A two-channel amplitude-amplitude monopulse radar system model was developed. The impulse response of the filters was determined by using inverse Laplace transform techniques. The output of the filters is applied to

logarithmic amplifiers. The derivation of the logarithmic amplifier was developed by MacAulay Brown Inc. (5:13-14). The output of the logarithmic amplifiers was subtracted which gave the error signal. A computer program, written in Fortran was developed to simulate this amplitude-amplitude monopulse system. The details of the amplitude-amplitude monopulse system is presented in Chapter II.

Assumptions

The assumptions used in the analysis of the impulse response on an amplitude-amplitude monopulse system are as follows:

(1) The response of the two channels to an impulsive waveform was not identical.

(2) The antenna coupled the impulsive signal to the feed element without degradation.

(3) The feed device coupled the impulsive signal to the receiver without degradation.

(4) With an impulsive signal supplied at the input to the mixer, the output of the mixer was an impulsive signal at the intermediate frequency (IF).

(5) The effects due to noise were neglected.

(6) The response of the logarithmic amplifiers were identical.

The first assumption was made to allow for imperfections between the channels of the radar to be modeled. If the assumption was made that the channels had the exact same

response, an error signal would not be created with any ECM signal. The second assumption was valid because the bandpass of the antenna is large enough to pass the main lobe of impulsive signals that could physically be generated. Although the feed device is constructed of waveguide and waveguide is dispersive the length of the feed is small enough to neglect the frequency spreading caused by the waveguide and this makes the third assumption valid. Steven Avery, a member of the Watkins-Johnson Company technical staff in the Engineering Development section of the Mixer Department, stated: "The response time of a mixer can be neglected if the input frequency is below 1000 GHz (1)." Although Mr. Avery believed this fourth assumption to be valid, he has not performed any testing on mixers with an impulsive type of input, and therefore this assumption may not be totally correct. The fifth assumption is valid if the impulsive ECM signal is large compared to any noise generated in the radar. The sixth assumption was made to keep the model as simple as possible.

Summary

It was apparent from the literature review that low duty cycle jamming may degrade the operation of an amplitude-amplitude monopulse radar system. This chapter has provided justification for this thesis, detailed the approached used to solve the problem, and outlined the assumptions used in the analysis of the problem. Chapter II

will provide a description of an amplitude-amplitude monopulse radar system and will present the details used in analyzing the radar. Chapter III will discuss the results of using this model. Chapter IV will present conclusions and recommendations relevant to this thesis.

II. Amplitude-Amplitude Monopulse System

Block Diagram

An amplitude-amplitude monopulse system is a system in which the angle information is contained in the amplitude patterns of the antenna and the angle discriminator uses the ratios of the amplitude patterns to determine the tracking error. A block diagram of an amplitude-amplitude monopulse system for target tracking in one coordinate is shown in Figure 1.

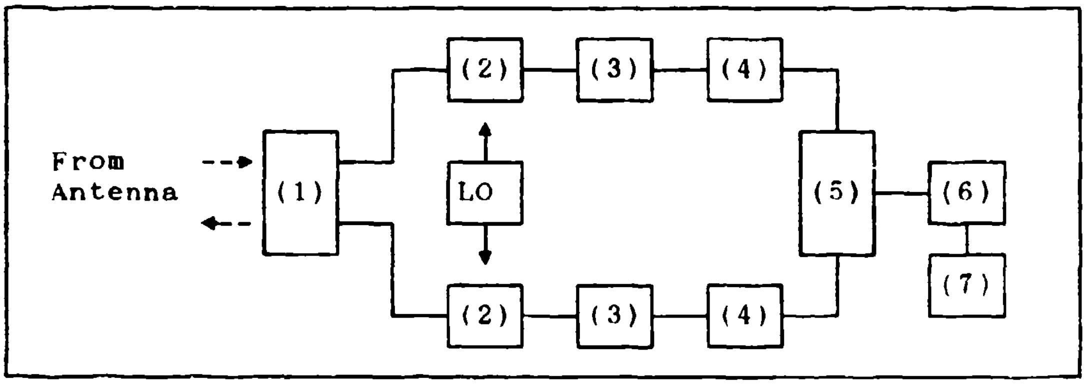

Figure 1. Block Diagram of an Amplitude-Amplitude Monopulse System for Target Tracking in One Coordinate (4:76)

(1) receiving/transmitting switch
(2) mixer
(3) logarithmic amplifier
(4) amplitude detector
(5) subtraction circuit
(6) error signal amp
(7) antenna control

In monopulse radar systems employing amplitude-comparison angle sensing, two identical overlapping antenna beam patterns are formed. When the target is offset by an angle from the boresight axis, the signal received through one pattern will have a greater amplitude than the signal received through the other pattern. The amplitude of the difference between the two patterns determines the magnitude of the angular offset from the boresight axis. The sign of the difference indicates the target direction (4:2). As can be seen from Figure 1, the received signal from one antenna will be processed by a different channel than the signal received from the other antenna. Each channel has it own mixer, amplifier, and detector. The output of the detectors is fed to a subtraction circuit to produce an error signal.

Analysis

One channel of an amplitude-amplitude monopulse receiver is shown in Figure 2.

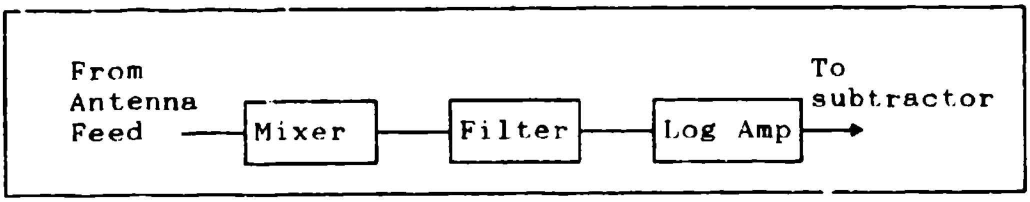

Figure 2. One Channel of an Amp-Amp Monopulse Receiver

As discussed in Chapter I, it was assumed the antenna, the feed system, and the mixer would not degrade an input of an impulsive type. It is well known that a mixer will produce spurious signals if its input is of a large value. It is assumed here the spurious signals caused by an impulsive type signal will be filtered by the IF filter. Therefore, the major component which will be affected by an impulsive ECM signal are the filters. After the signal is filtered it is passed to a logarithmic amplifier for signal compression. This leaves the filters, logarithmic amplifiers, and the subtraction circuitry to be modeled. A block diagram of the system is shown in Figure 3.

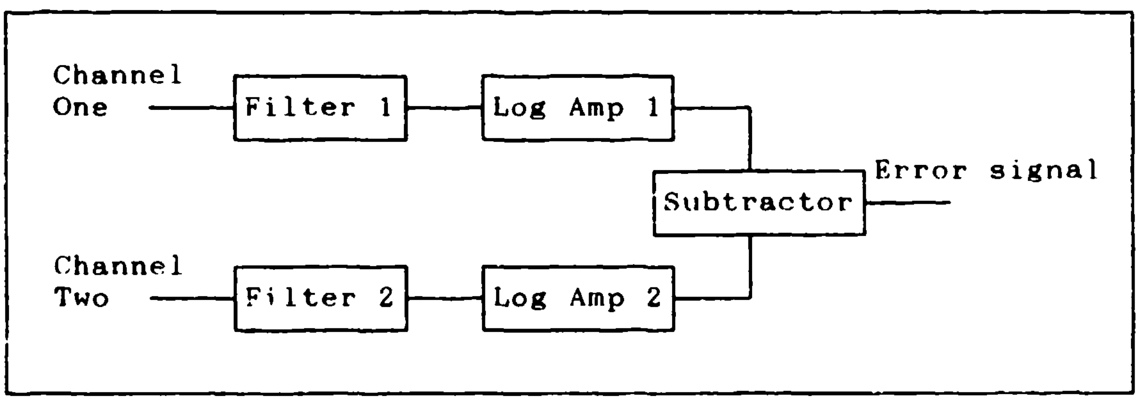

Figure 3. Block Diagram of Modeled System

Filters. The impulse response of the filters was determined by taking the inverse Laplace transform of the filter's transfer function. A three-pole filter and a five-pole filter were used in the analysis. The modeled filters are Butterworth type filters. These filters provide a simple model in the analysis of various imbalances between the receiver channels. The analysis is performed at video to keep the problem simple. One pole for both type filters was on the real axis and the other poles were complex conjugates.

Three-pole filter. The transfer function, H(s), of a three-pole filter is as follows:

$$H(s) = \{(s+x)(s+\alpha-j\beta)(s+\alpha+j\beta)\}^{-1} \tag{1}$$

The impulse response was found by taking the inverse transform.

$$h(t) = L^{-1}H(s) \tag{2}$$

and

$$h(t) = k_1\exp(-xt) + k_2\exp(-(\alpha-j\beta)t)$$

$$+ k_3\exp(-(\alpha+j\beta)t) \tag{3}$$

Solving for k_1, k_2, and k_3 leads to:

$$k_1 = (s+x)H(s) \quad ;s=-x \tag{4}$$

$$k_1 = \{(s+\alpha-j\beta)(s+\alpha+j\beta)\}^{-1} \quad ;s=-x \tag{5}$$

$$k_1 = \{(-x+\alpha-j\beta)(-x+\alpha+j\beta)\}^{-1} \tag{6}$$

Which leads to:

$$k_1 = \{((\alpha-x)^2 + \beta^2)\}^{-1} \tag{7}$$

And,

$$k_2 = (s+\alpha-j\beta)H(s) \quad ;s=-(\alpha-j\beta) \tag{8}$$

$$k_2 = \{(s+x)(s+\alpha+j\beta)\}^{-1} \quad ;s=-(\alpha-j\beta) \tag{9}$$

$$k_2 = \{(x-\alpha+j\beta)(2j\beta)\}^{-1} \tag{10}$$

Which leads to:

$$k_2 = \{(2j\beta)[(x-\alpha)^2+\beta^2]^{1/2}\exp(j\Psi)\}^{-1} \tag{11}$$

where,

$$\Psi = \tan^{-1}(\beta/x-\alpha) \tag{12}$$

Therefore,

$$k_2 = (\exp(-j\Psi))/2j\beta[(x-\alpha)^2+\beta^2]^{1/2} \tag{13}$$

And k_3 will be the complex conjugate of k_2,

$$k_3 = (\exp(j\Psi))/-2j\beta[(x-\alpha)^2+\beta^2]^{1/2} \tag{14}$$

Letting $\Psi' = -\Psi$ leads to:

$$k_2 = (\exp(j\Psi'))/2j\beta[(x-c)^2+\beta^2]^{1/2} \tag{15}$$

and

$$k_3 = (\exp(-j\Psi'))/-2j\beta[(x-\alpha)^2+\beta^2]^{1/2} \tag{16}$$

Therefore:

$$h(t) = (\exp(-xt))/[(\alpha-x)^2+\beta^2]$$

$$+ (\exp(j\Psi'))/2j\beta[(x-\alpha)^2+\beta^2]^{1/2}$$

$$+ (\exp(-j\Psi'))/-2j\beta[(x-\alpha)^2+\beta^2]^{1/2} \quad (17)$$

And using Euler's identity, we get for the impulse response

$$h(t) = (\exp(-xt))/[(\alpha-x)^2+\beta^2]$$

$$+ (\exp(-\alpha t))\sin(\Psi'+\beta t)/\beta[(x-\alpha)^2+\beta^2]^{1/2} \quad (18)$$

<u>Five-pole Filter.</u> The transfer function of a five-pole filter is given by

$$H(s) = \{(s+x)(s+\alpha_1-j\beta_1)(s+\alpha_1+j\beta_1)\}^{-1}$$
$$\times \{(s+\alpha_2-j\beta_2)(s+\alpha_2+j\beta_2)\}^{-1} \quad (19)$$

The impulse response g(t) is the inverse Laplace transform.

$$g(t) = L^{-1}H(s) \quad (20)$$

and,

$$g(t) = k_1\exp(-xt) + k_2\exp(-(\alpha_1-j\beta_1)t)$$

$$+ k_3\exp(-(\alpha_1+j\beta_1)t)$$

$$+ k_4\exp(-(\alpha_2-j\beta_2)t)$$

$$+ k_5\exp(-(\alpha_2+j\beta_2)t) \quad (21)$$

Using a procedure similar to that for the three-pole filter, we get for the constants of the five-pole filter,

$$k_1 = (s+x)H(s) \quad ;s=-x \tag{22}$$

$$k_2 = (s+(\alpha_1-j\beta_1))H(s) \quad ;s=-(\alpha_1-j\beta_1) \tag{23}$$

$$k_3 = \text{complex conjugate of } k_2 \tag{24}$$

$$k_4 = (s+(\alpha_2-j\beta_2))H(s) \quad ;s=-(\alpha_2-j\beta_2) \tag{25}$$

and

$$k_5 = \text{complex conjugate of } k_4 \tag{26}$$

After some manipulations these constants become:

$$k_1 = \{[(\alpha_1-x)^2+\beta_1{}^2][(\alpha_2-x)^2+\beta_2{}^2]\}^{-1} \tag{27}$$

$$k_2 = \{(2j\beta_1)(x-\alpha_1+j\beta_1)((\alpha_2-\alpha_1)+j(\beta_1-\beta_2))\}^{-1}$$

$$\times \{((\alpha_2-\alpha_1)+j(\beta_1+\beta_2))\}^{-1} \tag{28}$$

$$= \{(2j\beta_1)[(x-\alpha_1)^2+\beta_1{}^2]^{1/2}\exp(j\Psi_1)\}^{-1}$$

$$\times \{[(\alpha_2-\alpha_1)^2+(\beta_1-\beta_2)^2]^{1/2}\exp(j\Psi_2)\}^{-1}$$

$$\times \{[(\alpha_2-\alpha_1)^2+(\beta_1+\beta_2)^2]^{1/2}\exp(j\Psi_3)\}^{-1} \tag{29}$$

where,

$$\Psi_1 = \tan^{-1}(\beta_1/x-\alpha_1) \tag{30}$$

$$\Psi_2 = \tan^{-1}[(\beta_1-\beta_2)/(\alpha_2-\alpha_1)] \tag{31}$$

and,

$$\Psi_3 = \tan^{-1}[(\beta_1+\beta_2)/(\alpha_2-\alpha_1)] \tag{32}$$

Letting $\Psi_4 = -(\Psi_1 + \Psi_2 + \Psi_3)$ yields:

$$k_2 = (\exp(j\Psi_4))/(2j\beta_1)[(x-\alpha_1)^2+\beta_1{}^2]^{1/2}$$

$$\times \{[(\alpha_2-\alpha_1)^2+(\beta_1-\beta_2)^2]^{1/2}\}^{-1}$$

$$\times \{[(\alpha_2-\alpha_1)^2+(\beta_1+\beta_2)^2]^{1/2}\}^{-1} \tag{33}$$

k_3 being the complex conjugate of k_2 becomes,

$$k_3 = (\exp(-j\Psi_4))/(-2j\beta_1)[(x-\alpha_1)^2+\beta_1{}^2]^{1/2}$$

$$\times \{[(\alpha_2-\alpha_1)^2+(\beta_1-\beta_2)^2]^{1/2}\}^{-1}$$

$$\times \{[(\alpha_2-\alpha_1)^2+(\beta_1+\beta_2)^2]^{1/2}\}^{-1} \tag{34}$$

Solving for k_4:

$$k_4 = \{(2j\beta_2)[(x-\alpha_2)^2+\beta_2{}^2]^{1/2}\exp\Psi_5\}^{-1}$$

$$\times \{[(\alpha_1-\alpha_2)^2+(\beta_2-\beta_1)^2]^{1/2}\exp\Psi_6\}^{-1}$$

$$\times \{[(\alpha_1-\alpha_2)^2+(\beta_2+\beta_1)^2]^{1/2}\exp\Psi_7\}^{-1} \tag{35}$$

where,

$$\Psi_5 = \tan^{-1}(\beta_2/(x-\alpha_2) \tag{36}$$

$$\Psi_6 = \tan^{-1}((\beta_2-\beta_1)/(\alpha_1-\alpha_2)) \tag{37}$$

and,

$$\Psi_7 = \tan^{-1}((\beta_2+\beta_1)/(\alpha_1-\alpha_2)) \tag{38}$$

Letting $\Psi_8 = -(\Psi_5 + \Psi_6 + \Psi_7)$ leads to:

$$k_4 = (\exp(\Psi_8))/(2j\beta_2)[(x-\alpha_2)^2+\beta_2^2]^{1/2}$$

$$\times \{[(\alpha_1-\alpha_2)^2+(\beta_2-\beta_1)^2]^{1/2}\}^{-1}$$

$$\times \{[(\alpha_1-\alpha_2)^2+(\beta_2+\beta_1)^2]^{1/2}\}^{-1} \tag{39}$$

k_5 being the complex conjugate of k_4 becomes,

$$k_5 = (\exp(-\Psi_8))/(-2j\beta_2)[(x-\alpha_2)^2+\beta_2^2]^{1/2}$$

$$\times \{[(\alpha_1-\alpha_2)^2+(\beta_2-\beta_1)^2]^{1/2}\}^{-1}$$

$$\times \{[(\alpha_1-\alpha_2)^2+(\beta_2+\beta_1)^2]^{1/2}\}^{-1} \tag{40}$$

Plugging equations 27, 34, 35, 39, and 40 into equation 21 and using Euler's identity yields:

$$g(t) = (\exp(-xt))/[(\alpha_1-x)^2+\beta_1^2][(\alpha_2-x)^2+\beta_2^2]$$

$$+ 1/[(\alpha_2-\alpha_1)^2+(\beta_1-\beta_2)^2]^{1/2}[(\alpha_2-\alpha_1)^2+(\beta_1+\beta_2)^2]^{1/2}$$

$$\times \{\exp(-\alpha_1 t)\sin(\Psi_4+\beta_1 t)/\beta_1[(x-\alpha_1)^2+\beta_1^2]^{1/2}$$

$$+ \exp(-\alpha_2 t)\sin(\Psi_8+\beta_2 t)/\beta_2[(x-\alpha_2)^2+\beta_2^2]^{1/2}\} \tag{41}$$

which is the impulse response of a five-pole filter.

Logarithmic Amplifier. The following model of a logarithmic amplifier was derived by MacAulay Brown Inc. (5:13).

$$y = \begin{cases} Kx & ;0 \leq x \leq x' \\ A\log(x/x') + B & ;x \geq x' \end{cases} \tag{42}$$

where y is the output, x the input, x′ is the threshold of the logarithmic amplifier and K is the amplifier gain. To solve for A and B the equation must be evaluated at x = x′ which leads to:

$$Kx' = A\log(x'/x') + B \tag{43}$$

Therefore,

$$B = Kx' \tag{44}$$

Setting the derivatives equal at x = x′ yields:

$$\frac{dy}{dx} = K = \frac{A}{(x\ln(10))} \tag{45}$$

Therefore,

$$A = K(x'\ln(10)) \tag{46}$$

Substituting A and B back into the basic model

$$y = \begin{cases} Kx & ;x \leq x' \\ (K(x'\ln(10))\log(x/x') + Kx' & ;x \geq x' \end{cases} \tag{47}$$

This can be rewritten as:

$$y = \begin{cases} Kx & ; x \leq x' \\ K(x'\ln(10))\log x - K(x'\ln(10))\log x' + Kx' & \end{cases} \qquad (48)$$

to model of logarithmic amplifier.

Monopulse Radar Model. A block diagram of the model developed for this thesis is shown in Figure 3. The equation used to model the filter was either equation 18 or equation 41, depending if a three-pole or a five-pole filter was used. The logarithmic amplifier was modeled by using equation 48. The subtraction circuit was modeled by subtracting the output of logarithmic amplifier 2 from the output of logarithmic amplifier 1. Fortran computer programs were written to model both the three-pole filter radar and the five-pole filter radar. The Fortran code for these models is presented in the Appendix. Chapter III presents the results of using the models for various pole positions.

III. Results

This chapter presents the results of using the amplitude-amplitude monopulse radar models with various imbalances between the channels of the radar. The response of the model was determined assuming the target was on boresight of the radar. This means the amplitude of the impulse signal going into each channel filter was the same. For the various imbalances the response of the filters is first presented, then the output of the logarithmic amplifiers is given, and finally the output of the subtraction circuitry is shown. The computer programs presented in the Appendix were used to obtain the data used to create the plots. This data was imported to LOTUS™ and then used to create the plots.

Three-Pole Filter

The transfer function for a three-pole filter was given in Chapter II equation 1. If the filters of the two channels were matched the values for x, σ, and β would be equivalent. To simulate an imbalance between the two channels various values of x, α, and β were chosen. Table 1 presents the various unbalanced conditions used in the analysis of using the amplitude-amplitude monopulse radar model with three-pole filters. The values for the poles were chosen to provide a wide sample of imbalanced

conditions. The values of the poles normally would lie on the Butterworth unit circle. The poles which do not have a magnitude of one provide the imbalance between the two receiver channels. Imbalanced condition 1 provides a condition which normally would occur in a radar. Imbalanced condition 2 creates a large imbalance between the receiver channels, and imbalanced conditions 3, 4, and 5 provide different amounts of imbalance between the two.

Table 1. Imbalanced Conditions for Analysis With Three-Pole Filter.

Imbalanced Condition	Filter 1 Poles	Filter 2 Poles
Balanced	x = 1.0 α = 0.81 β = 0.59	x = 1.0 α = 0.81 β = 0.59
1	x = 1.0 α = 0.81 β = 0.59	x = 1.0 α = 0.81 β = 0.71
2	x = 1.0 α = 0.81 β = 0.59	x = 0.5 α = 0.81 β = 0.71
3	x = 1.0 α = 0.81 β = 0.59	x = 1.0 α = 0.95 β = 1.14
4	x = 1.0 α = 0.5 β = 0.25	x = 1.0 α = 0.95 β = 1.14
5	x = 1.0 α = 0.25 β = 0.75	x = 1.0 α = 0.95 β = 0.25

The first condition used with the model was one with matched filters. This created a balanced condition. This condition was used to insure the model was operating correctly. The filter response for this balanced condition is shown in Figure 4. As expected the response of the filters was identical. The output of the logarithmic amplifiers is shown in Figure 5. The output of the subtraction circuitry is shown in Figure 6, and as expected the output was zero.

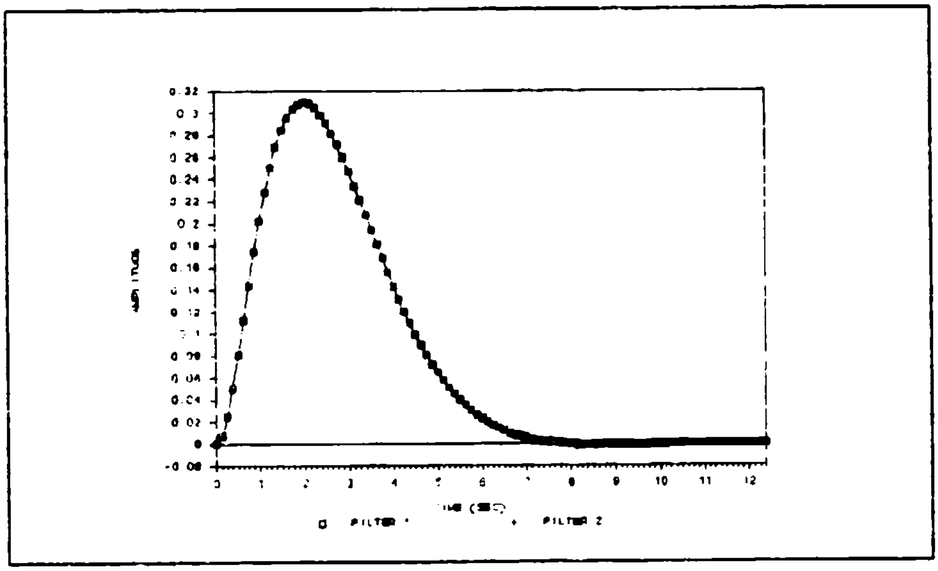

Figure 4. Filter Response for a Balanced Condition

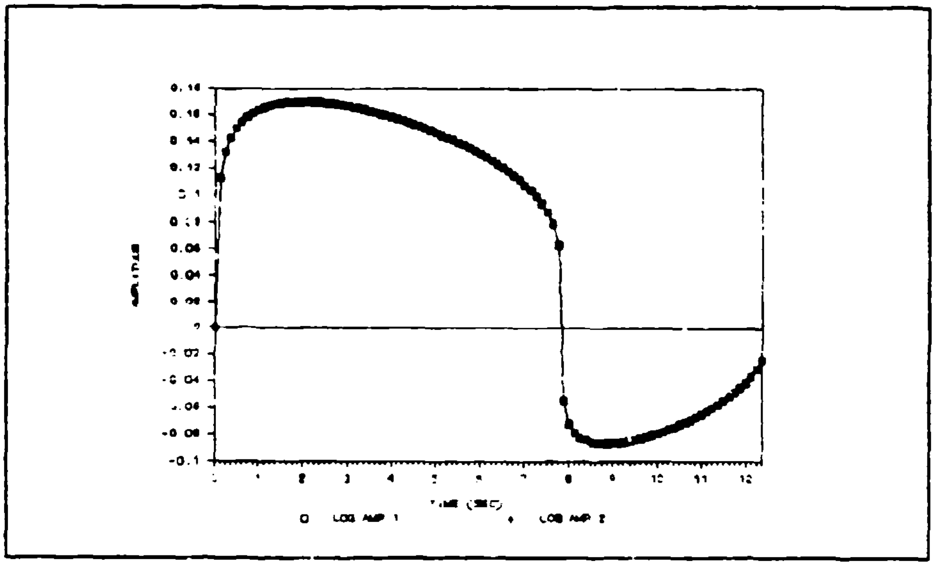

Figure 5. Output of Logarithmic Amplifier (Balanced Condition)

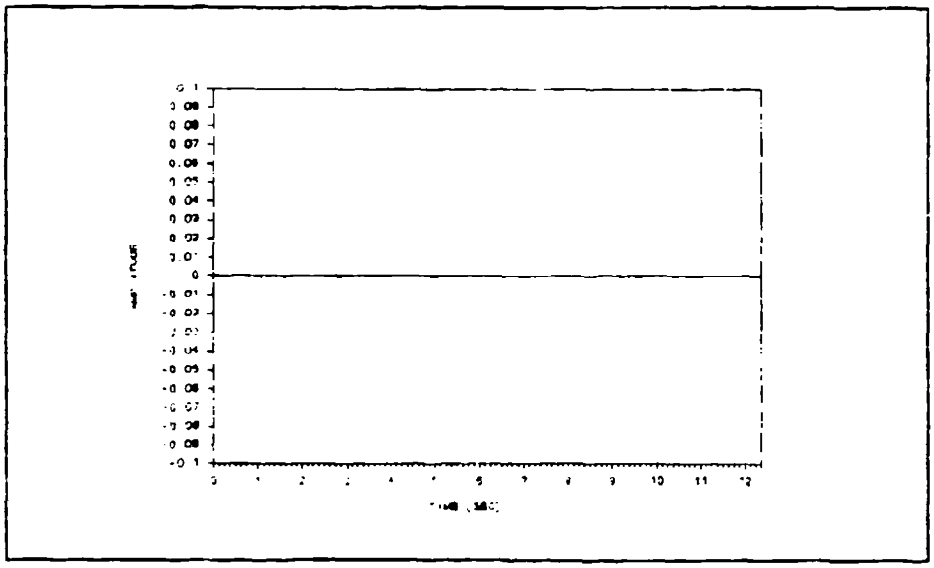

Figure 6. Output of Subtraction Circuitry (Balanced Condi ion)

The filter response for imbalanced condition 1 is shown in Figure 7. This amount of imbalance would be expected between filters in a typical monopulse radar system. As can be seen from Figure 8, the output of the logarithmic amplifiers is different, but the difference is not very substantial until four seconds after the impulse has arrived at the filters. The output of the subtraction circuitry is shown in Figure 9.

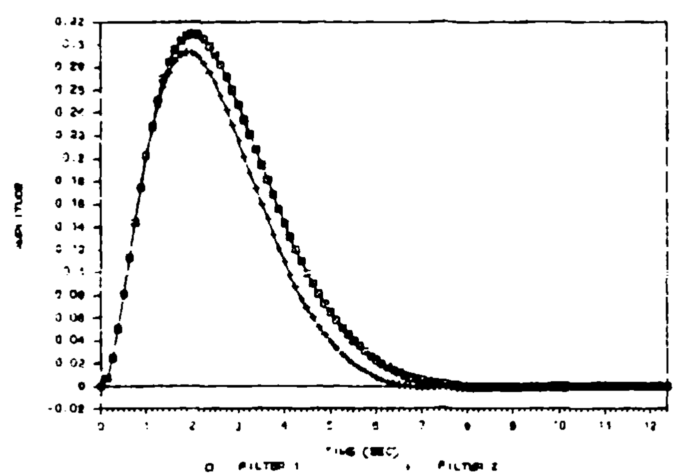

Figure 7. Filter Response (Imbalanced Condition 1)

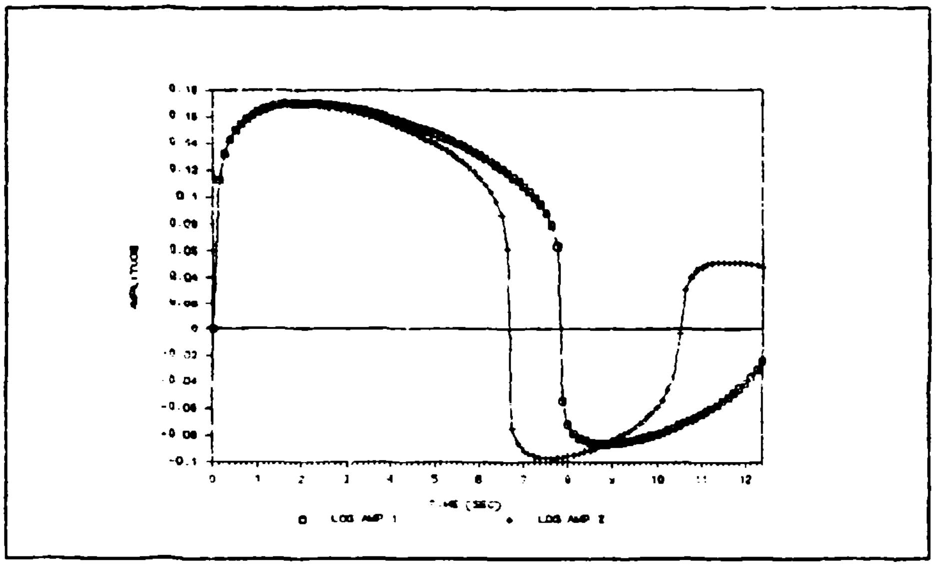

Figure 8. Output of Logarithmic Amplifiers (Imbalanced Condition 1)

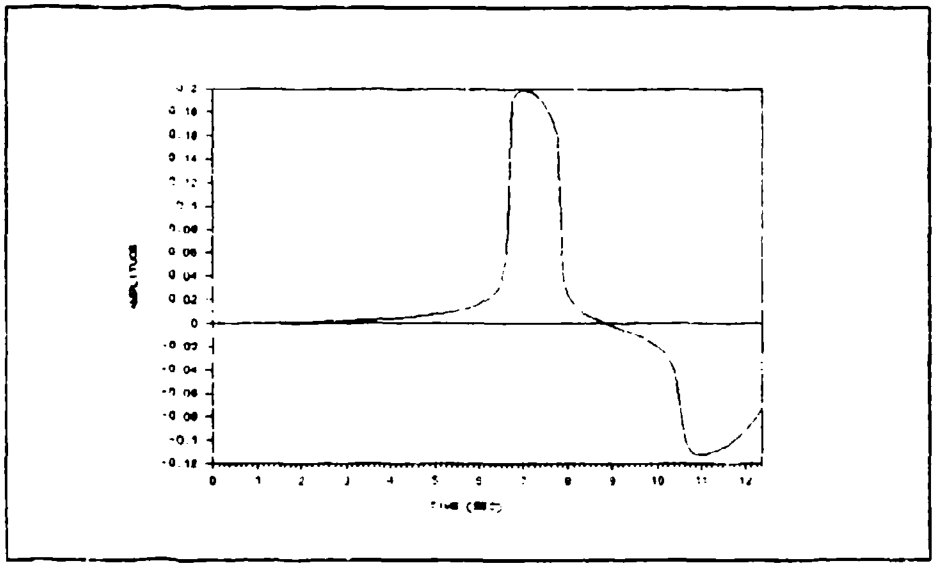

Figure 9. Output of Subtraction Circuitry (Imbalanced Condition 1)

The filter response for imbalanced condition 2 is shown in Figure 10. This condition simulates a large imbalance between the filters. This condition should not occur in practice. The output of the logarithmic amplifiers is shown in Figure 11 and the output of the subtraction circuitry is shown in Figure 12. As can be seen from Figure 12 there is a non-zero output of the subtraction circuitry at time equal to zero. This means there will be a tracking error due to the imbalance of the filters.

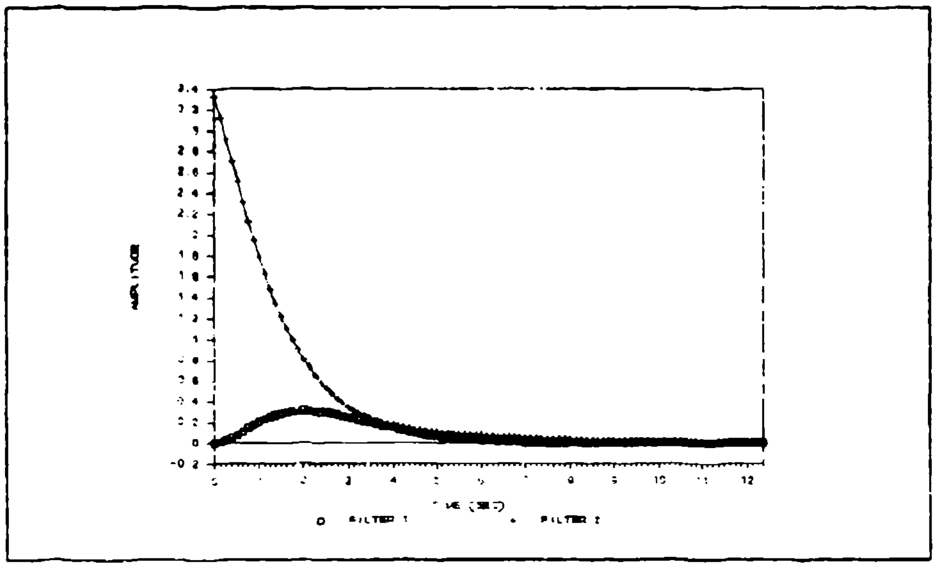

Figure 10. Filter Response (Imbalanced Condition 2)

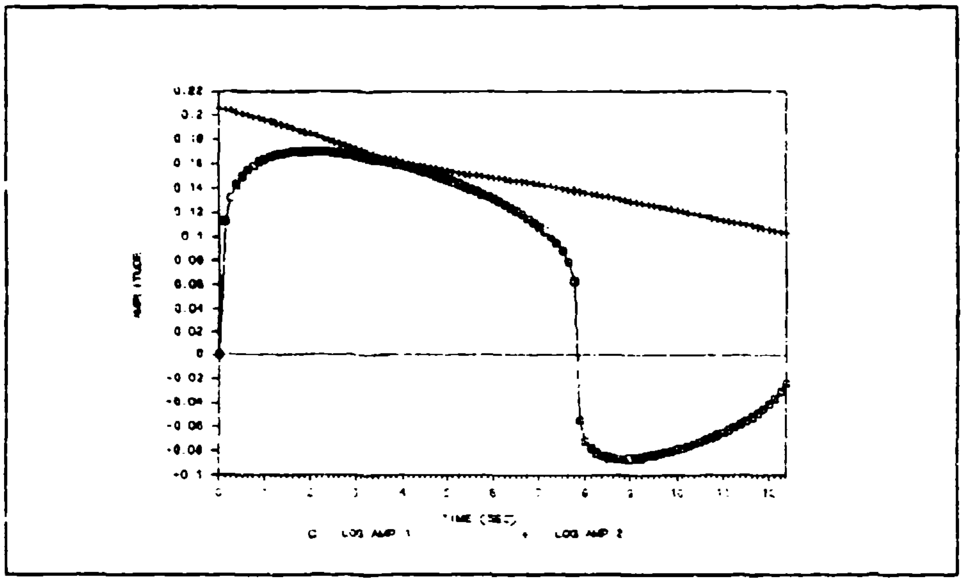

Figure 11. Output of Logarithmic Amplifiers (Imbalanced Condition 2)

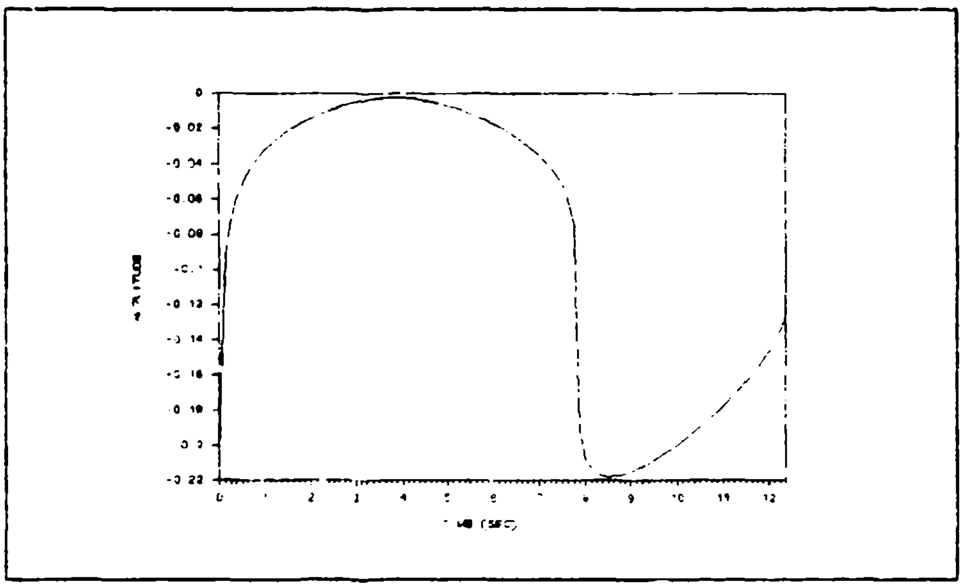

Figure 12. Output of Subtraction Circuitry (Imbalanced Condition 2)

Figure 13 shows the filter response for imbalanced condition 3. This condition presents a larger imbalance between the filters than imbalanced condition 1, but is more practical than imbalanced condition 2. Figure 14 presents the output of the logarithmic amplifiers and the output of the subtraction circuitry is provided in Figure 15.

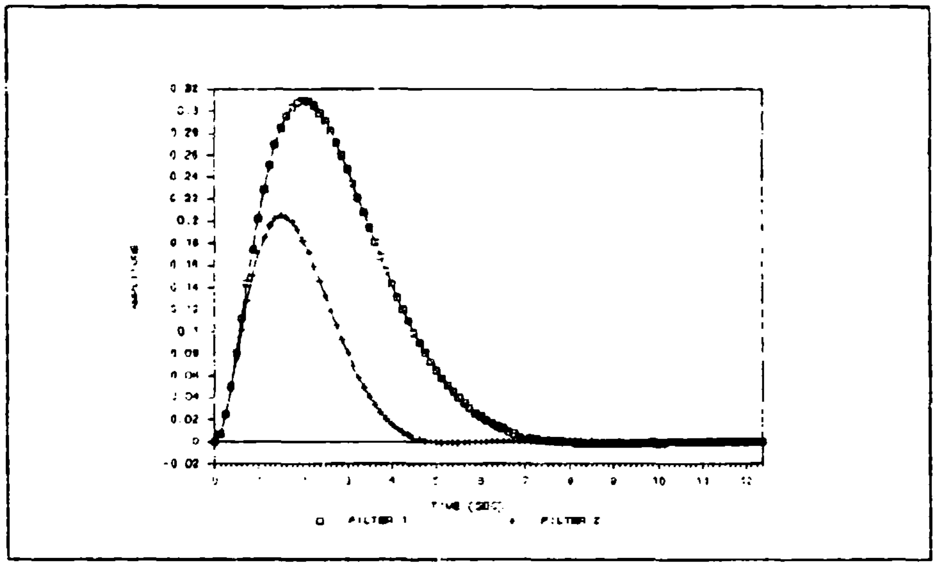

Figure 13. Filter Response (Imbalanced Condition 3)

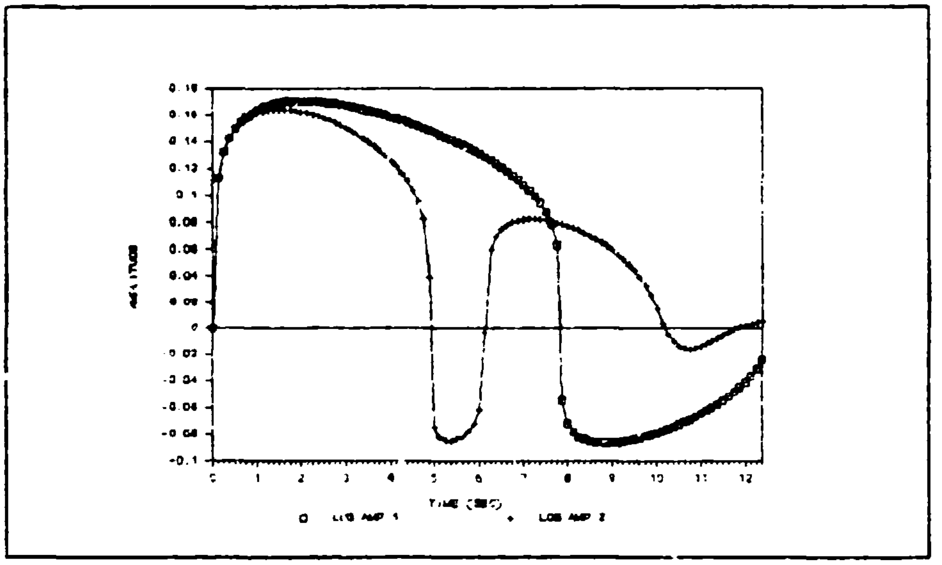

Figure 14. Output of Logarithmic Amplifiers (Imbalanced Condition 3)

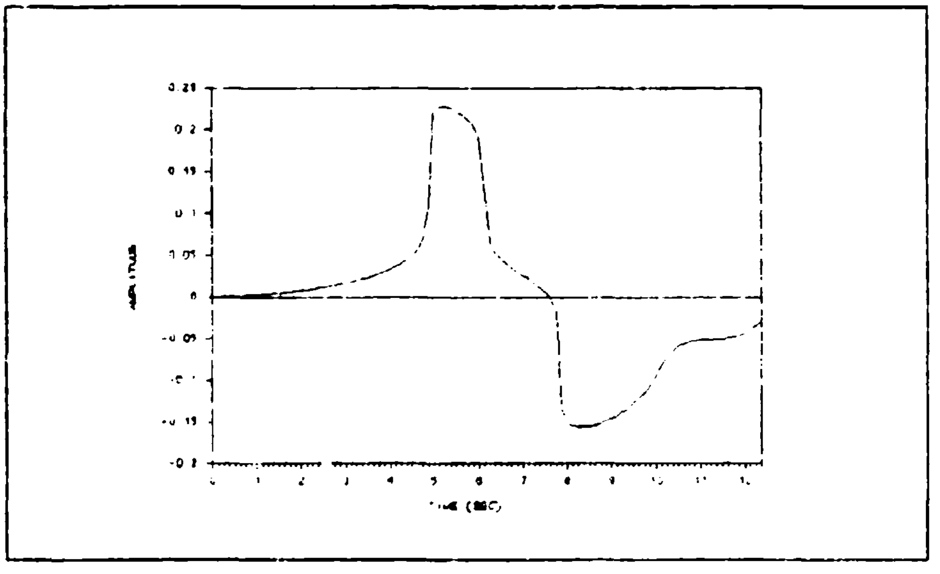

Figure 15. Output of Subtraction Circuitry (Imbalanced Condition 3)

The filter response for imbalanced condition 4 is shown in Figure 16. This condition presents a larger imbalance than of imbalanced condition 3. The filters of an amplitude-amplitude monopulse radar would not have this much imbalance between them. The output of the logarithmic amplifiers is presented in Figure 17 and the output of the subtraction circuitry is shown in Figure 18.

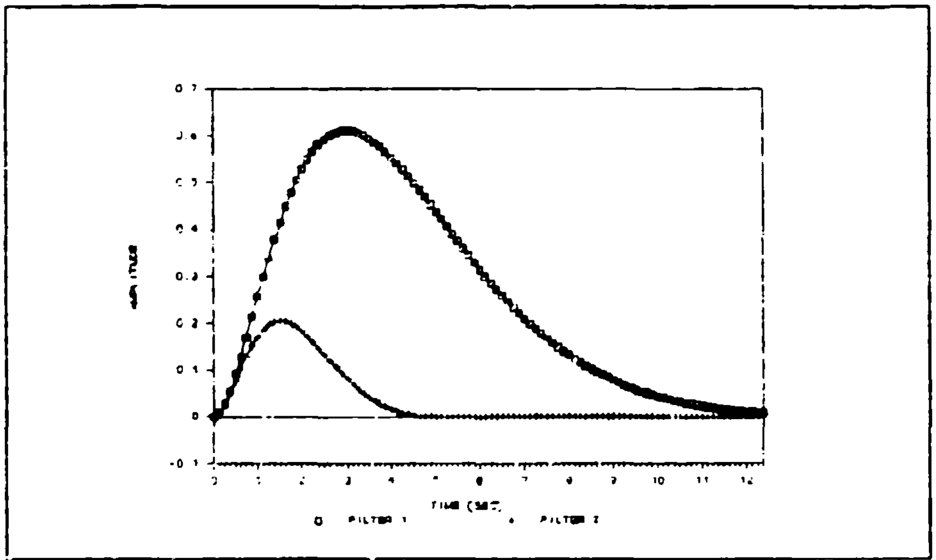

Figure 16. Filter Response (Imbalanced Condition 4)

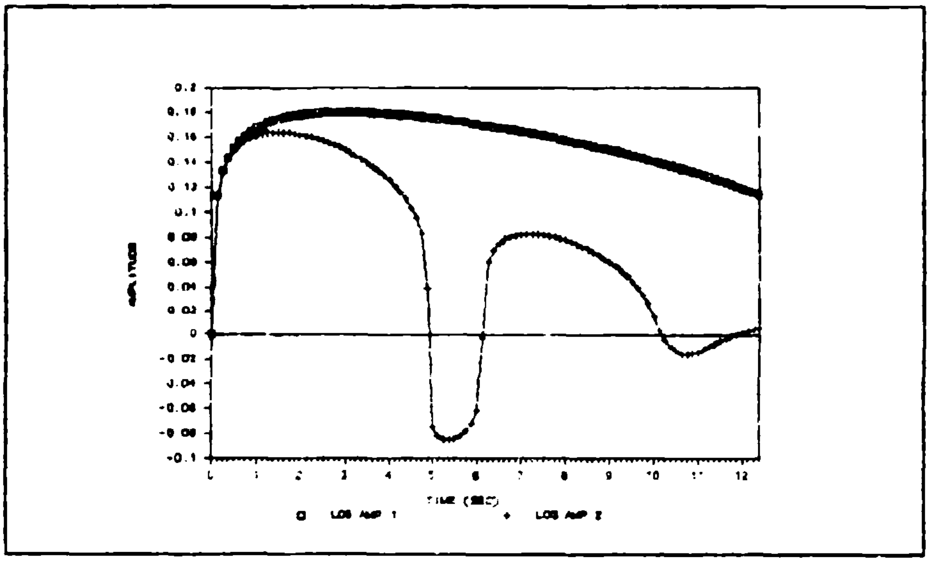

Figure 17. Output of Logarithmic Amplifiers (Imbalanced Condition 4)

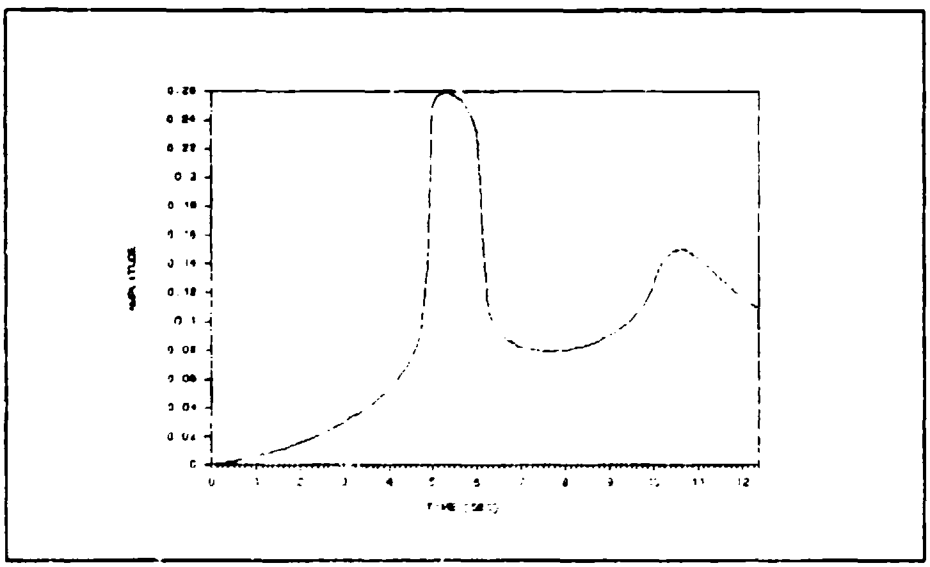

Figure 18. Output of Subtraction Circuitry (Imbalanced Condition 4)

The filter response for imbalanced condition 5 is presented in Figure 19. This condition presents a larger imbalance between the filters than imbalanced condition 4. The output of the logarithmic amplifiers is shown in Figure 20 and the output of the subtraction circuitry is given in Figure 21.

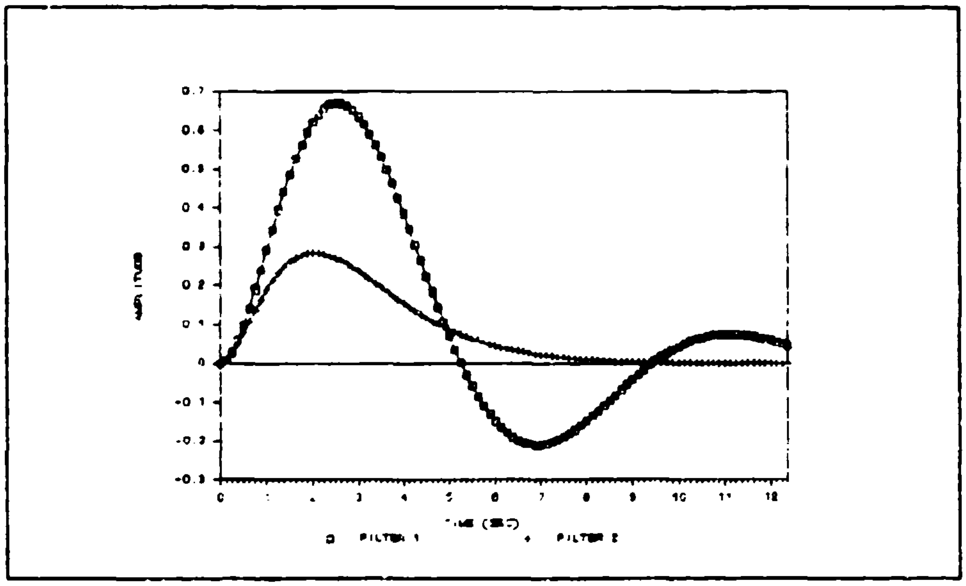

Figure 19. Filter Response (Imbalanced Condition 5)

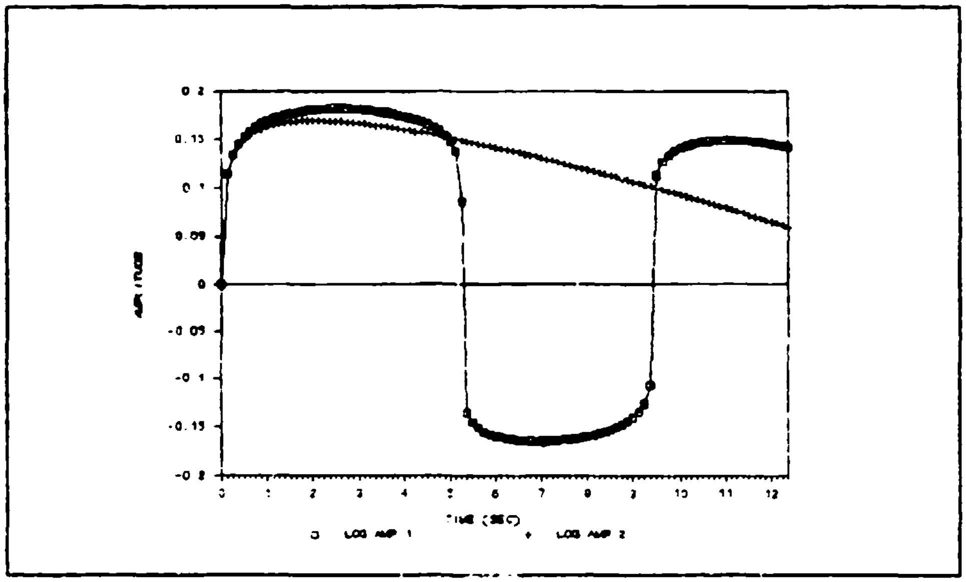

Figure 20. Output of Logarithmic Amplifiers (Imbalanced Condition 5)

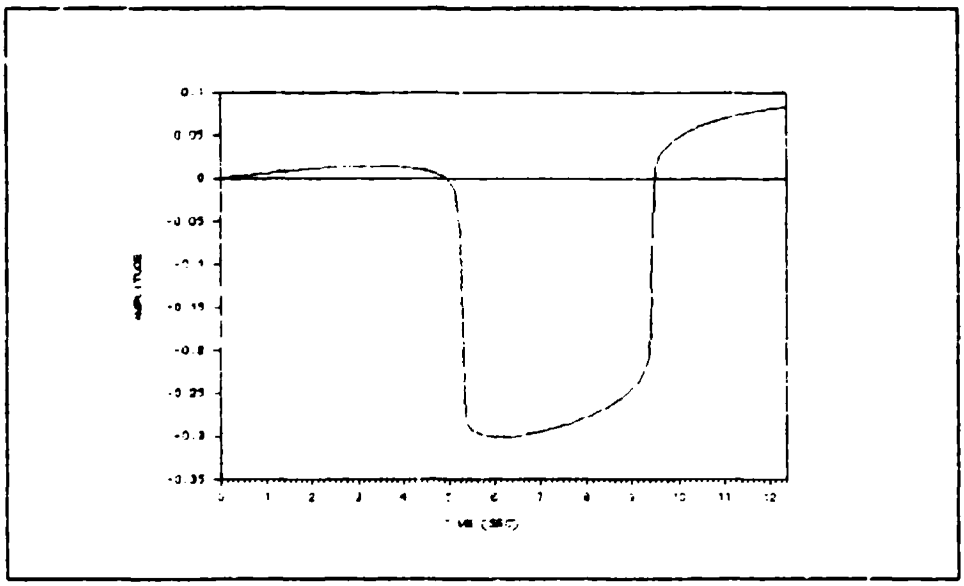

Figure 21. Output of Subtraction Circuitry (Imbalanced Condition 5)

Five-Pole Filter

The results of using the five-pole filter in the model is comparable to the results using the three-pole filter. Table 2 presents the various imbalanced conditions used in the five-pole filter model. In Table 2, S1 represents the pole on the real axis S23 represents the second and third poles, which are complex conjugates, and S45 represents the fourth and fifth poles. As with the three-pole model, the values for the poles were selected to present a wide range of imbalanced conditions. Imbalanced condition F1 presents an imbalance which would normally occur. Imbalanced condition F2 provides a large imbalance between the receiver

Table 2. Imbalanced Conditions for Analysis With Five-Pole Filter.

Imbalanced Condition	Filter 1 Poles	Filter 2 Poles
F1	S1 = -1.0, 0.0 S23 = -0.81,±0.59 S45 = -0.31,±0.95	S1 = -1.0, 0.0 S23 = -0.81,±0.71 S45 = -0.31,±1.14
F2	S1 = -1.0, 0.0 S23 = -0.81,±0.59 S45 = -0.31,±0.95	S1 = -0.5, 0.0 S23 = -0.81,±0.71 S45 = -0.31,±1.14
F3	S1 = -1.0, 0.0 S23 = -0.81,±0.59 S45 = -0.31,±0.95	S1 = -1.0, 0.0 S23 = -0.95,±0.59 S45 = -0.31,±1.14
F4	S1 = -1.0, 0.0 S23 = -0.50,±0.85 S45 = -0.31,±0.95	S1 = -1.0. 0.0 S23 = -0.95,±0.59 S45 = -0.31,±1.14

channels and imbalanced conditions F3 and F4 present imbalances between the two.

The filter responses for imbalanced condition F1 is shown in Figure 22. This imbalance would be typical of filters used in an amplitude-amplitude monopulse radar system. The output of the logarithmic amplifiers is shown in Figure 23 and the output of the subtraction circuitry is presented in Figure 24.

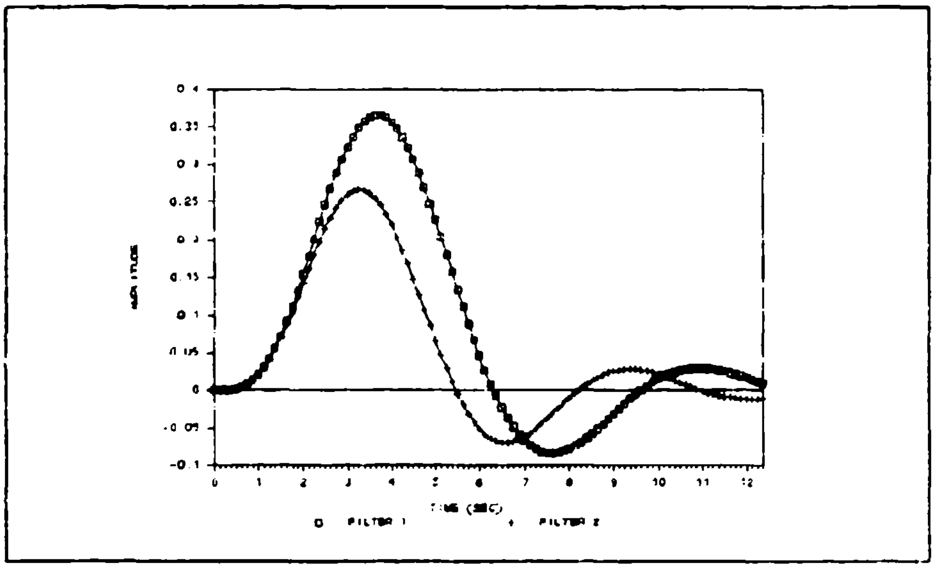

Figure 22. Filter Response (Imbalanced Condition F1)

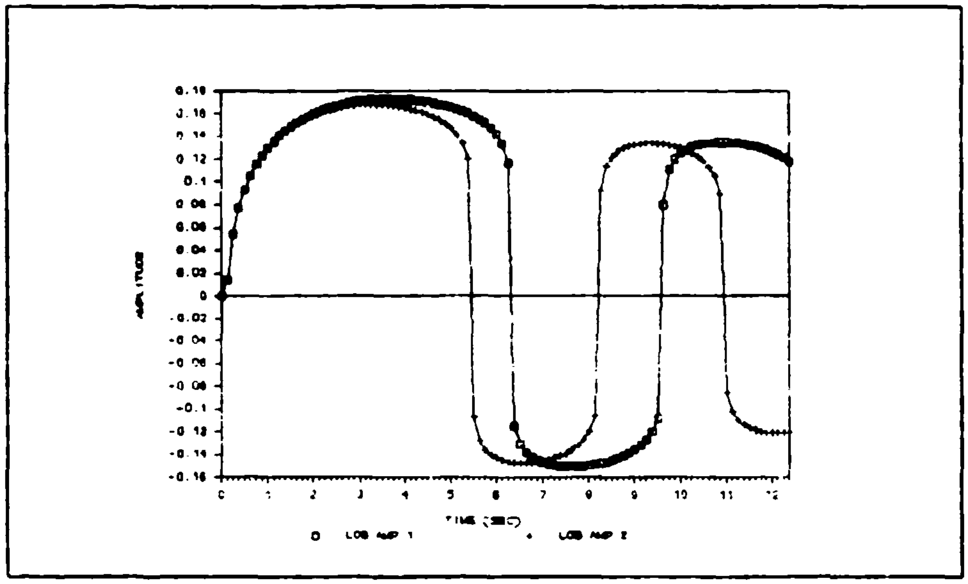

Figure 23. Output of Logarithmic Amplifiers (Imbalanced Condition F1)

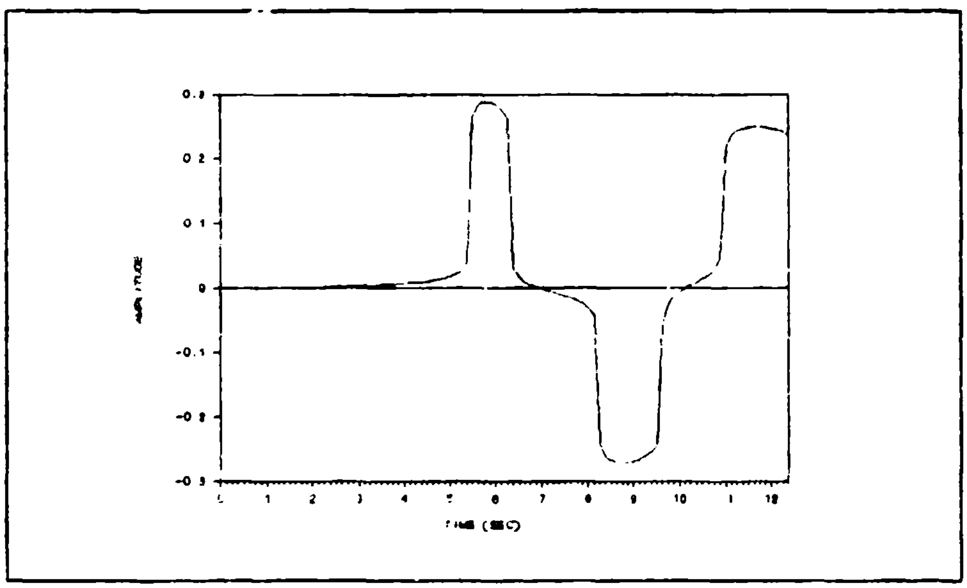

Figure 24. Output of Subtraction Circuitry (Imbalanced Condition F1)

The filter response for imbalanced condition F2 is shown in Figure 25. This condition simulates a condition in which the imbalance between the filter is very large. This condition should not happen in practice. Figure 26 presents the output of the logarithmic amplifiers and Figure 27 shows the output of the subtraction circuitry. As can be seen from the figures this condition produces an error signal at time near zero.

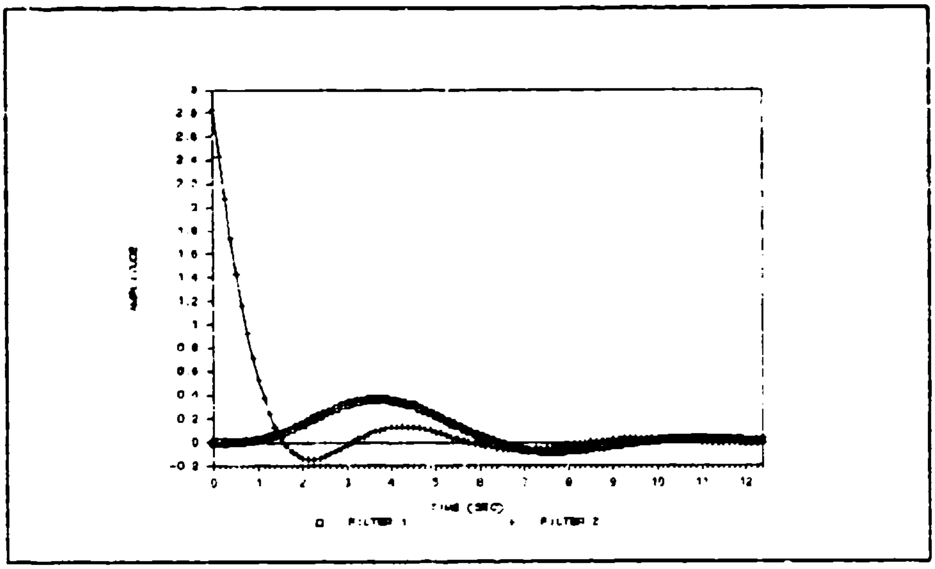

Figure 25. Filter Response (Imbalanced Condition F2)

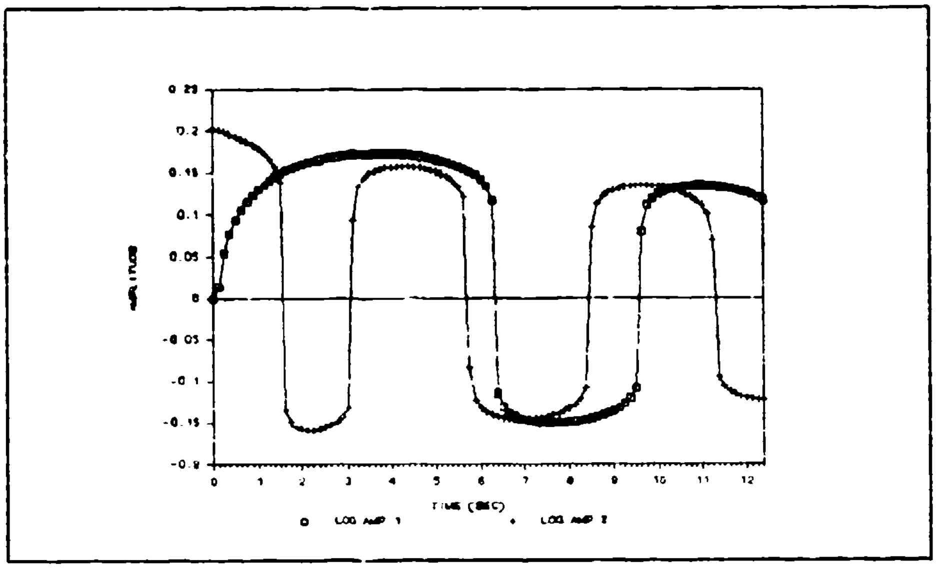

Figure 26. Output of Logarithmic Amplifiers (Imbalanced Condition F2)

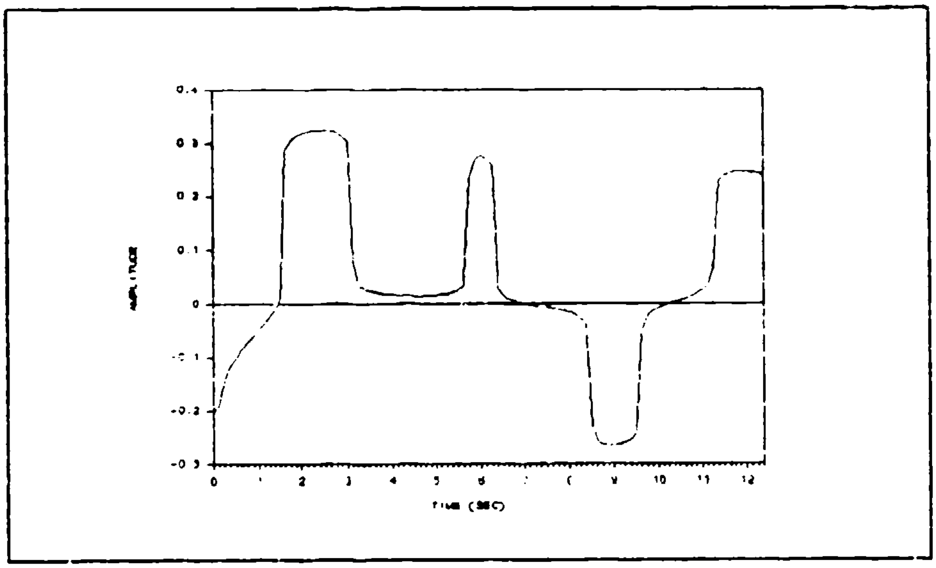

Figure 27. Output of Subtraction Circuitry (Imbalanced Condition F2)

Figure 28 presents the filter response for the imbalanced condition F3. This condition has a larger imbalance than imbalanced condition F1 but, it is more realistic than imbalanced condition F2. The output of the logarithmic amplifiers is presented in Figure 29 and the output of the subtraction circuitry is provided in Figure 30.

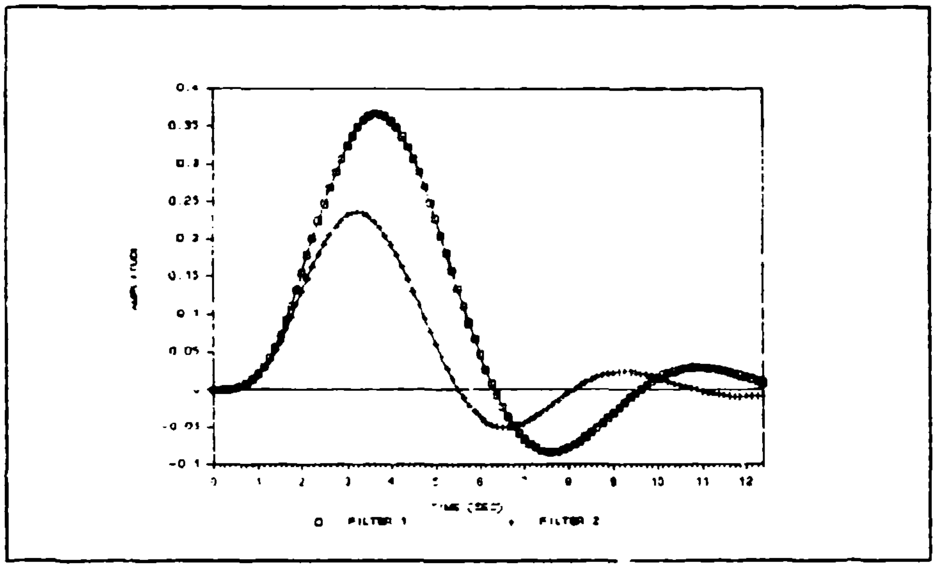

Figure 28. Filter Response (Imbalanced Condition F3)

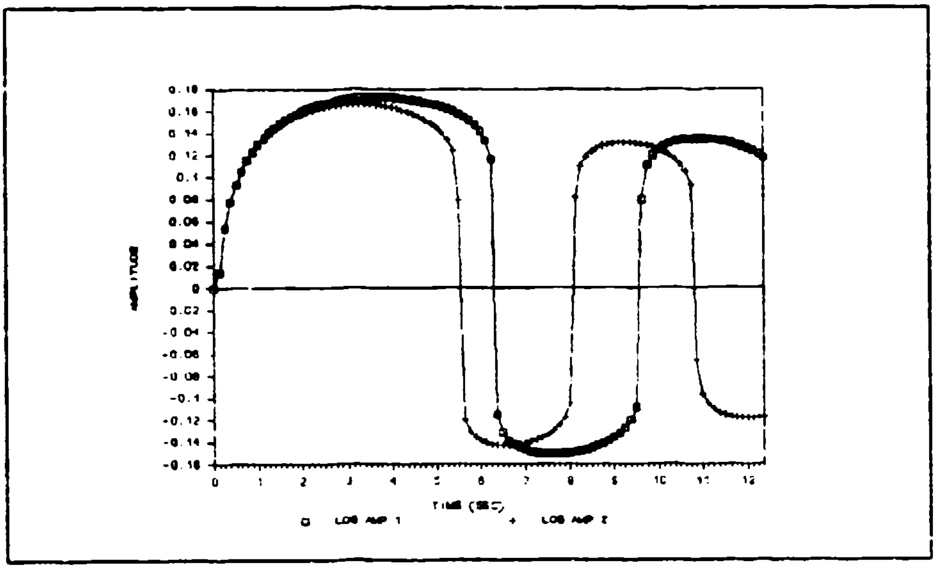

Figure 29. Output of Logarithmic Amplifiers (Imbalanced Condition F3)

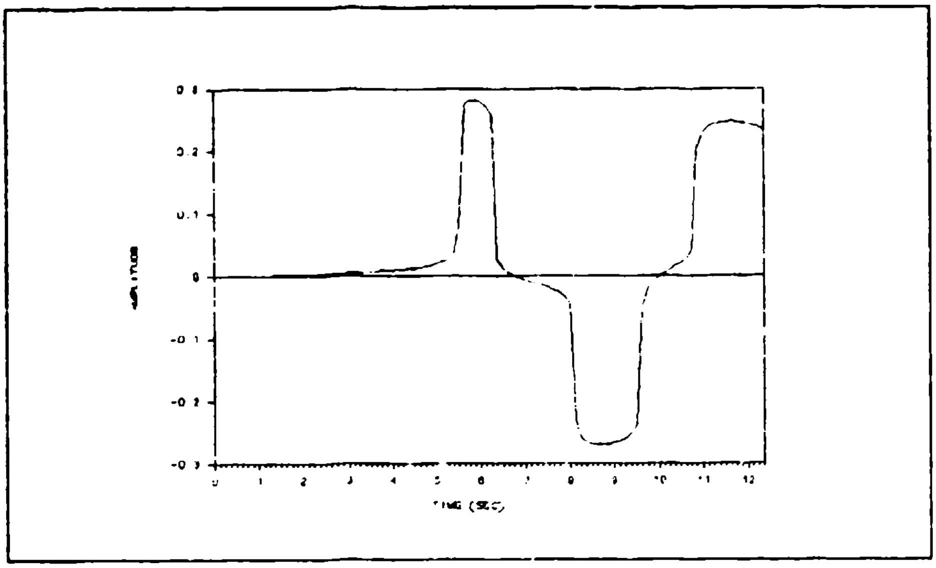

Figure 30. Output of Subtraction Circuitry (Imbalanced Condition F3)

The filter response for imbalanced condition F4 is shown in Figure 31. This condition presents a larger imbalance between the filters than imbalanced condition F3. The output of the logarithmic amplifiers is presented in Figure 32 and the output of the subtraction circuitry is shown in Figure 33.

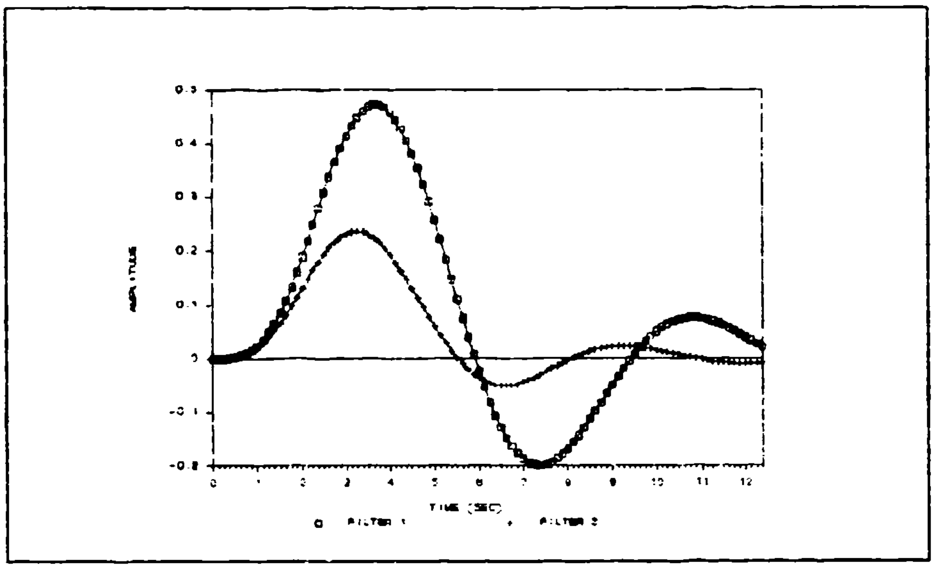

Figure 31. Filter Response (Imbalanced Condition F4)

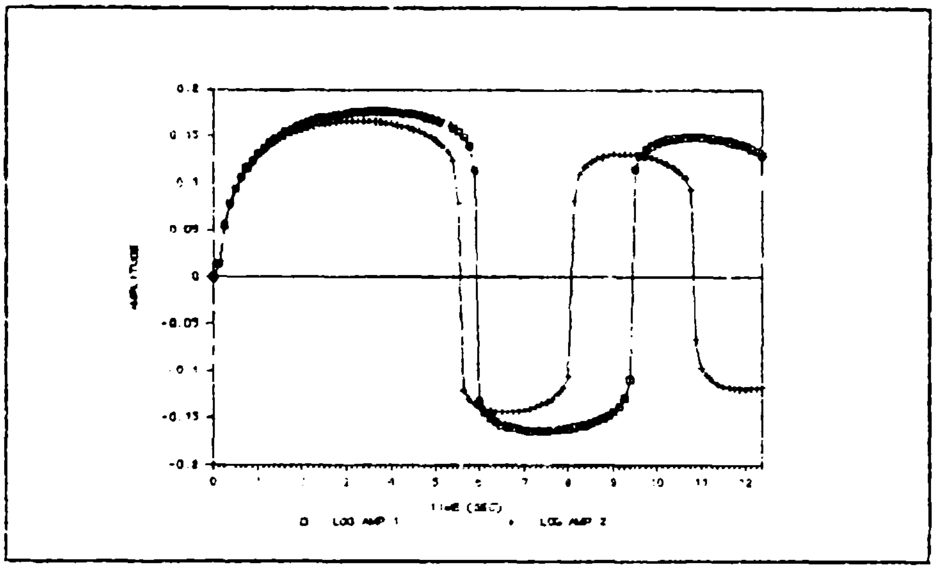

Figure 32. Output of Logarithmic Amplifiers (Imbalanced Condition F4)

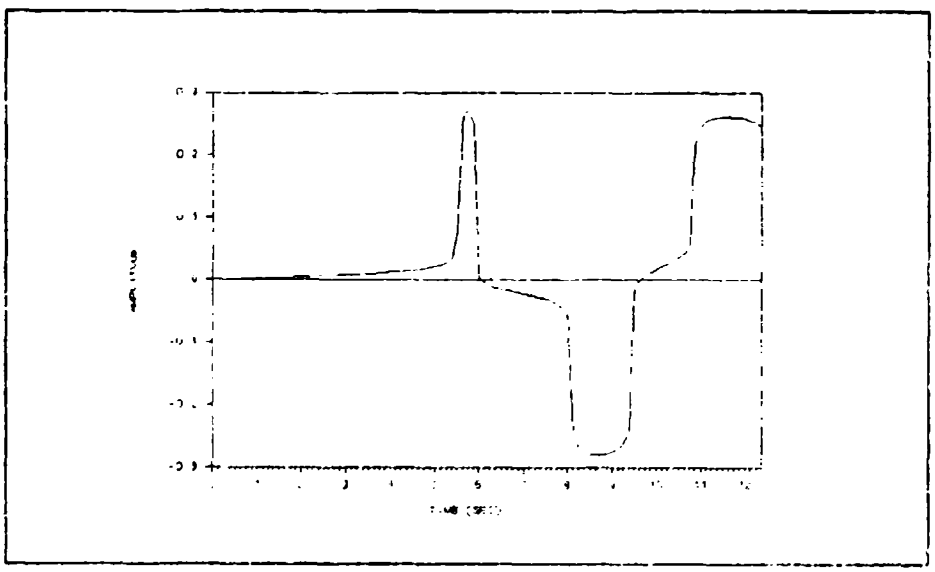

Figure 33. Output of Subtraction Circuitry (Imbalanced Condition F4)

Discussion

The results obtained using the models of the amplitude-amplitude monopulse radar systems show the error caused by an impulsive type of input signal was dependent on the imbalance between the receiver channels. For a typical imbalance condition the error found was not substantial until four to six seconds after the impulse is applied to the filters. This is well out of the range gate of the radar. Although this type of signal does not produce errors during the range gate, the residual affects due to this signal may produce angle tracking errors. The range gate is usually applied after the filters in the receiving channel. Therefore, the impulsive signal will cause the filter to "ring" as shown in the Figures for the filter response. Due to the imbalance between the receiver channels, the filters will have a different response and produce an error signal out of the subtraction circuitry. This signal is applied to the servo system and if the error signal is large enough a break lock may occur. If the impulse signal is applied on every returned pulse, the radar may be able to lock on the jamming signal. Therefore, the impulsive signal should be applied once every six to eight seconds. This will allow the errors due to the impulsive signal to be created but keep the probability of the range circuitry seeing the jamming low. This means this type of signal can cause

errors in the angle sensing circuits of the radar while all evidence of its presence is kept from the range gate display. It must be emphasized the value of this type of signal as an ECM signal is totally dependent on the imbalance between the receiver channels of the radar and the impulse response of the filters. Therefore, individual radar systems will be affected differently by this signal. Most radars will have some receiver channel imbalance and the impulsive signal will produce tracking errors.

IV. Conclusions and Recommendations

Conclusions

This thesis has provided a simple model of an amplitude-amplitude monopulse radar system to determine the impulse response for various imbalances between the receiving channels. A model for a three-pole filter and a model for a five-pole filter was developed for this analysis. Logarithmic amplifiers were used in the channels to provide signal compression. This analysis showed that, unless there was a large imbalance between the receiving channels, the impulsive signal does not produce a substantial tracking error until four to six seconds after the impulse is applied to the filters. If the impulsive signal is applied to the radar once every six to eight seconds, errors may be produced in the angle tracking circuits without the signal being detected by the range gate circuitry or the operator. The angle error caused by this type of signal is dependent on the imbalance in the frequency response of the receiver channels. The amount of imbalance between the receiver channels is difficult to determine and will be different for each radar system. For a typical imbalance between receiver channels the impulsive signal should produce angle tracking errors.

Recommendations

It is recommended for follow on research the following be accomplished:

(1) The models be updated to include intermediate amplifiers with automatic gain control circuitry.

(2) The models be updated to include the effects of antenna and feed systems.

(3) Impact on the radar using a physically realizable impulse be determined.

(4) Determine the optimum period between impulse signals.

(5) Experimental results be obtained using impulsive ECM techniques against monopulse radars.

(6) Determine the sensitivity of the error signal versus the pole placement.

Appendix: Computer Programs

This appendix contains the computer program listings for the models developed for this thesis. The computer programs were written in Fortran and were ran on a Sierra PC/XT with a math coprocessor. Double precision was used to reduce computational error near time equal to zero. The listing using the three-pole filters is presented first, then the listing using the five-pole filter is presented. For the three-pole filter case equation 18 was used to model the filters. For the five-pole case equation 41 was used to model the filters. For both cases equation 48 was used to model the logarithmic amplifier.

Three-Pole Filter

```
C
C     THIS PROGRAM COMPUTES THE IMPULSE RESPONSE OF AN
C     AMPLITUDE-AMPLITUDE MONOPULSE RADAR USING A
C     THREE-POLE FILTER.  EQUATION 18 WAS USED TO MODEL
C     THE FILTERS AND EQUATION 48 WAS USED TO MODEL THE
C     LOGARITHMIC AMPLIFIERS.  THE GAIN, K, OF THE
C     LOGARITHMIC AMPLIFIER WAS SET TO 1500 AND THE
C     THRESHOLD WAS SET TO 0.00001.
C
      DOUBLE PRECISION GA(100),U(100),C1(100),D1(100),E1(100)
      DOUBLE PRECISION R1(100),GB(100),C2(100),D2(100)
      DOUBLE PRECISION R2(100),A1,B1,AT1,BT1,G0,G1,G2
      DOUBLE PRECISION S1,S2,Y1,Y2,W1,W2,THRES,E2(100)
C
      OPEN(6,STATUS='UNKNOWN',FILE='RESPO7.DAT')
      OPEN(7,STATUS='UNKNOWN',FILE='RESPO8.DAT')
C
C     POLES FOR FILTER ONE
C
      X1=1.0
      A1=0.81
      B1=0.59
C
C     POLES FOR FILTER TWO
C
      X2=1.0
      AT1=0.81
      BT1=0.71
C
C     GAIN AND THRESHOLD FOR LOG AMP
C
      G0=1500.
      THRES=0.00001
      G1=G0*DLOG(10.)*THRES
      G2=G0*THRES-G1*DLOG10(THRES)
C
C  DETERMINE PHASE FACTORS FOR IMPULSE RESPONSE
C
      S1=-(DATAN((B1)/(X1-A1)))
      S2=-(DATAN((BT1)/(X2-AT1)))
C
C
C
      Y1=(((A1-X1)**2)+(B1**2))
      Y2=(((AT1-X2)**2)+(BT1**2))
      W1=DSQRT((X1-A1)**2+(B1**2))
      W2=DSQRT((X2-AT1)**2+(BT1**2))
C
C
C
```

```
      WRITE(6,30)
30    FORMAT(9X,'TIME(SEC)',4X,'LOGAMP1',4X,
     1'LOGAMP2',4X,'DIFF',/)
      WRITE(7,40)
40    FORMAT(7X,'TIME (SEC)',3X,'FILT1 RESP',3X,
     1'FILT2 RESP',/)
      DO 20 I=1,100
      U(I)=((1.0/8.)*FLOAT(I))-(1./8.)
      C1(I)=(DEXP(-(X1*U(I)))/Y1)
      C2(I)=(DEXP(-(X2*U(I)))/Y2)
      D1(I)=DEXP(-(A1*U(I)))
      D2(I)=DEXP(-(AT1*U(I)))
      E1(I)=DSIN(S1+(B1*U(I)))
      E2(I)=DSIN(S2+(BT1*U(I)))
C
C     IMPULSE RESPONSE OF FILTERS
C
      GA(I)=(C1(I))+((D1(I)*E1(I))/(B1*W1))
      GB(I)=(C2(I))+((D2(I)*E2(I))/(BT1*W2))
C
C     COMPUTE OUTPUT OF LOG AMPS
C
      IF(ABS(GA(I)).LE.THRES) THEN
      R1(I)=G0*GA(I)
      ELSE
      R1(I)=DSIGN((G1*DLOG10(ABS(GA(I)))+G2),GA(I))
      END IF
C
      IF(ABS(GB(I)).LE.THRES) THEN
      R2(I)=G0*GB(I)
      ELSE
      R2(I)=DSIGN((G1*ALOG10(ABS(GB(I)))+G2),GB(I))
      END IF
      D(I)=R1(I)-R2(I)
      WRITE(6,60) U(I),R1(I),R2(I),D(I)
      WRITE(7,70) U(I),GA(I),GB(I)
20    CONTINUE
60    FORMAT(4F15.6)
70    FORMAT(3F15.6)
      CLOSE(UNIT=6)
      CLOSE(UNIT=7)
      END
```

Five-Pole Filter

```
C     THIS PROGRAM COMPUTES THE IMPULSE RESPONSE OF AN
C     AMPLITUDE-AMPLITUDE MONOPULSE RADAR USING A FIVE-POLE
C     FILTER.  EQUATION 41 WAS USED TO MODEL THE FILTERS AND
C     EQUATION 48 WAS USED TO MODEL THE LOGARITHMIC
C     AMPLIFIERS.  THE GAIN, K, OF THE LOGARITHMIC AMPLIFIER
C     WAS SET TO 1500, AND THE THRESHOLD WAS SET TO 0.00001.
C
      DOUBLE PRECISION GA(100),U(100),C1(100),D1(100)
      DOUBLE PRECISION R1(100),GB(100),C2(100),D2(100)
      DOUBLE PRECISION H2(100),R2(100),D(100),GC(100)
      DOUBLE PRECISION A1,A2,B1,B2,AT1,BT1,AT2,BT2,G0,G1,G2
      DOUBLE PRECISION S1,S2,S3,S4,S5,S6,S7,S8,ST1,ST2,ST3
      DOUBLE PRECISION ST4,ST5,ST6,ST7,ST8,Y1,Y2,X1,X2
      DOUBLE PRECISION T1,T2,V1,V2,THRES,GA1,GA2,GB1,GB2
      DOUBLE PRECISION F1(100),F2(100),Z1,Z2,W1,W2,XT1,XT2
      DOUBLE PRECISION E1(100),E2(100),H1(100)
      OPEN(6,STATUS='UNKNOWN',FILE='RESPO5.DAT')
      OPEN(7,STATUS='UNKNOWN',FILE='RESPO6.DAT')
C
C     POLES FOR FILTER ONE
C
      XT1=1.0
      A1=0.81
      A2=0.31
      B1=0.59
      B2=0.95
C
C     POLES FOR FILTER TWO
C
      XT2=1.0
      AT1=0.81
      AT2=0.31
      BT1=0.71
      BT2=1.14
C
C     GAIN AND THRESHOLD FOR LOG AMP
C
      G0=1500.
      THRES=0.00001
      G1=G0*DLOG(10.)*THRES
      G2=G0*THRES-G1*DLOG10(THRES)
C
C  DETERMINE PHASE FACTORS FOR IMPULSE RESPONSE
C
      S1=DATAN((B1-B2)/(A2-A1))
      S2=DATAN((B1+B2)/(A2-A1))
      S3=DATAN((B1)/(XT1-A1))
      S4=-(S3+S2+S1)
      S5=DATAN((B2-B1)/(A1-A2))
```

```
      S6=DATAN((B2+B1)/(A1-A2))
      S7=DATAN((B2)/(XT1-A2))
      S8=-(S5+S6+S7)
C
C
      ST1=DATAN((BT1-BT2)/(AT2-AT1))
      ST2=DATAN((BT1+BT2)/(AT2-AT1))
      ST3=DATAN((BT1)/(XT2-AT1))
      ST4=-(ST3+ST2+ST1)
      ST5=DATAN((BT2-BT1)/(AT1-AT2))
      ST6=DATAN((BT2+BT1)/(AT1-AT2))
      ST7=DATAN((BT2)/(XT2-AT2))
      ST8=-(ST5+ST6+ST7)
C
C
C
      Y1=(((A1-XT1)**2)+(B1**2))*(((A2-XT1)**2)+(B2**2))
      Y2=(((AT1-XT2)**2)+(BT1**2))*(((AT2-XT2)**2)+(BT2**2))
      X1=DSQRT((A2-A1)**2+(B1-B2)**2)
      X2=DSQRT((AT2-AT1)**2+(BT1-BT2)**2)
      Z1=DSQRT((A2-A1)**2+(B1+B2)**2)
      Z2=DSQRT((AT2-AT1)**2+(BT1+BT2)**2)
      W1=DSQRT((XT1-A1)**2+B1**2)
      W2=DSQRT((XT2-AT1)**2+BT1**2)
      V1=DSQRT((XT1-A2)**2+B2**2)
      V2=DSQRT((XT2-AT2)**2+BT2**2)
C
C
C
      WRITE(6,30)
30    FORMAT(9X,'TIME (SEC)',4X,'LOGAMP1',4X,
     1'LOGAMP2',4X,'DIFF',/)
      WRITE(7,40)
40    FORMAT(7X,'TIME (SEC)',3X,'FILT1 RESP',3X,
     1'FILT2 RESP',/)
      DO 20 I=1,100
      U(I)=((1.0/8.)*FLOAT(I))-(1./8.)
      C1(I)=DEXP(-(U(I)))/Y1
      C2(I)=DEXP(-(U(I)))/Y2
      D1(I)=DEXP(-(A1*U(I)))
      D2(I)=DEXP(-(AT1*U(I)))
      E1(I)=DSIN(S4+(B1*U(I)))
      E2(I)=DSIN(ST4+(BT1*U(I)))
      F1(I)=DEXP(-(A2*U(I)))
      F2(I)=DEXP(-(AT2*U(I)))
      H1(I)=DSIN(S8+(B2*U(I)))
      H2(I)=DSIN(ST8+(BT2*U(I)))
      T1 = X1*Z1
      T2 = X2*Z2
      GA1=D1(I)/(B1*W1)
      GA2=D2(I)/(BT1*W2)
      GB1=F1(I)/(B2*V1)
```

```
      GB2=F2(I)/(BT2*V2)
C
C     IMPULSE RESPONSE OF FILTERS
C
      GA(I)=(C1(I))+((1/T1)*((GA1*E1(I))+(GB1*H1(I))))
      GB(I)=(C2(I))+((1/T2)*((GA2*E2(I))+(GB2*H2(I))))
C
C     COMPUTE OUTPUT OF LOG AMPS
C
      IF(ABS(GA(I)).LE.THRES) THEN
      R1(I)=G0*GA(I)
      ELSE
      R1(I)=DSIGN((G1*DLOG10(ABS(GA(I)))+G2),GA(I))
      END IF
C
      IF(ABS(GB(I)).LE.THRES) THEN
      R2(I)=G0*GB(I)
      ELSE
      R2(I)=DSIGN((G1*ALOG10(ABS(GB(I)))+G2),GB(I))
      END IF
C
C     COMPUTE THE SUBTRACTOR OUTPUT
C
      D(I)=R1(I)-R2(I)
      WRITE(6,60) U(I),R1(I),R2(I),D(I)
      WRITE(7,70) U(I),GA(I),GB(I)
20    CONTINUE
60    FORMAT(4F15.6)
70    FORMAT(3F15.6)
      CLOSE(UNIT=6)
      CLOSE(UNIT=7)
      END
```

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VITA

Captain Dennis L. Tackett was born on 16 September 1952 in Portsmouth, Virginia. He graduated from high school in Suffolk, Virginia, in 1970. He enlisted in the United States Air Force in 1971 and served as a Precision Measuring Equipment Technician being stationed at Eglin AFB, Florida, Woomera AS, Australia, and Shaw AFB, South Carolina. He was accepted into the Airman Education Commissioning Program in 1978. He attended the University of Florida, from which he received the degree of Bachelor of Science in Electrical Engineering with Honors in June 1981. Upon graduation he attended Officers Training School, Lackland AFB, Texas. He received his commission on 1 October 1981. He was then assigned to Warner Robins Air Logistics Center, Robins AFB, Georgia as an Electronic Warfare Systems Engineer. In October 1984 he was assigned to the Tactical Air Warfare Center, Eglin AFB, Florida as an Electronic Warfare Systems Engineer and served there until entering the School of Engineering, Air Force Institute of Technology, in May 1987.

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE

3. DISTRIBUTION / AVAILABILITY OF REPORT
Approved for public release; distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
AFIT/GE/ENG/88D-52

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION
School of Engineering

6b. OFFICE SYMBOL (If applicable)
AFIT/ENG

7a. NAME OF MONITORING ORGANIZATION

6c. ADDRESS (City, State, and ZIP Code)
Air Force Institute of Technology
Wright-Patterson AFB OH 45433-6583

7b. ADDRESS (City, State, and ZIP Code)

8a. NAME OF FUNDING / SPONSORING ORGANIZATION
AFEWC

8b. OFFICE SYMBOL (If applicable)
SAX

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS (City, State, and ZIP Code)
Air Force Electronic Warfare Center
San Antonio TX 78243-5000

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
ON THE IMPULSE RESPONSE OF MONOPULSE RADARS

12. PERSONAL AUTHOR(S)
Dennis L. Tackett, Capt USAF

13a. TYPE OF REPORT
MS Thesis

13b. TIME COVERED
FROM ________ TO ______

14. DATE OF REPORT (Year, Month, Day)
1988 December

15. PAGE COUNT
66

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
17	04	03
17	09	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Radar jamming, radar countermeasures, Monopulse radar

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Thesis Chairman: Dr. Vittal Pyati
Associate Professor of Electrical Engineering

Abstract: This study developed an analytical model of an amplitude-amplitude monopulse radar to determine the response due to an impulsive input signal. The model consisted of a three or five-pole filter impulse response, logarithmic amplifiers, and subtraction circuitry. A two-channel amplitude-amplitude monopulse system was modeled.

The results of the analysis showed that an impulsive signal would not cause a substantial tracking error until four to six seconds after the impulse arrives at the input to the

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL
Dr. Vittal Pyati

22b. TELEPHONE (Include Area Code)
(513)-255-3576

22c. OFFICE SYMBOL
AFIT/ENG

DD Form 1473, JUN 86 Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

19. cont.

filters, which is well out of the range gate of the radar. This signal may produce errors in the angle tracking circuits of the radar without being seen by the range circuitry or an operator. It is recommended that experimental results be obtained.